VERIFICATION OF IMPACT MODELS FOR PYROSHOCK SIMULATION

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ABSTRACT

This paper describes the development of a numerical model in ANSYS Explicit Dynamics of a pyroshock simulator. The shock resulting from projectile impact on a resonant plate and the characteristics of the resulting shock response spectrum at the test item interface are modelled and compared to experimental results. The model provides insight into the effect of the projectile impact variables that are used to match the target shock response spectrum. The study was conducted during the commissioning process of a pyroshock events simulator manufactured by SERMS s.r.l, that has been installed as part of the National Satellite Test Facility at the Rutherford Appleton Laboratories.

1. PYROSHOCK SIMULATOR

The SERMS Pyroshock Simulator consists of an air cannon which is used to propel a captive steel projectile at a precise velocity to impact a vertically suspended resonant plate to which the item under test is attached (Figure 1). The impact conditions are varied in order to produce the specified shock response spectrum (SRS) at the test item interface.

To achieve the correct SRS a proprietary software package is used. The test machine is supplied with the SERMS Pyroshock Management (SPM) prediction programme which is useful in providing a starting point. This uses a database of previous tests to determine the starting conditions for a particular target spectrum. The output is expressed in terms of the pressure used to propel the projectile and the type of pad used at the impact face. However, it relies on a database of prior test results and does not provide any prediction of the effects of changes in the test machine setup. In practise a certain amount of trial and error is required to tune the SRS to the target requirement.

A model which predicted the broad trends of the output SRS as a function of impact characteristics would be valuable in providing alternative tuning strategies.

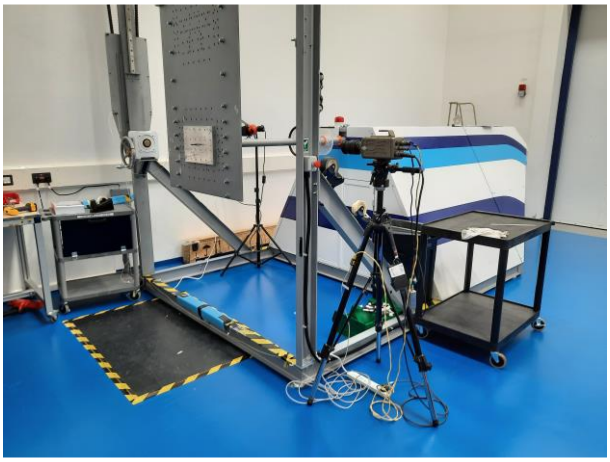

Figure 1 The SERMS Pyroshock Simulator at RAL Space configured for a blank test in the z (out of plane) direction

Previous studies have shown that it is possible to model the response of a reverberant structure using harmonic analysis, usually after modal analysis to calibrate damping [1]. An input shock spectrum derived from an appropriate test requirement is then applied to the model as an input to produce the required response. It is also possible to input force histories to a suitable model using the ANSYS APDL RESP command, but this appears to be limited to very simple input pulses such as half sine or saw tooth. A paper by Kim [2] offers some useful insight into the variables such as impactor mass that control the SRS in a pyroshock simulator and used an experimentally measured impact force history as an input. An alternative, which is pursued in the present study is to use an explicit solver to model the input impact and apply this to the numerically modelled shock simulator rig and then derive the SRS at the test item interface.

The SRS is tuned by changing the impact parameters to control the overall level of the SRS. Pulse shaping by choice of suitable pad materials has been studied for space test applications and also for use in Hopkinson bar test machines which have some similarities [3, 4]. A useful introduction to pulse shaping is given by Amari, [5] which includes some information on pulse shaping using metallic pads.

For the present study the guidelines of the pyroshock simulator manufacturer were followed which recommend pads consisting of combinations of EPDM rubber, Nylon and/or paper positioned at the projectile impact point. These are used to tune the SRS, although in the present study a set of relatively simple cases were chosen using only a soft aluminium and/or a rubber impact pad.

2. EXPERIMENAL SETUP

A series of tests were conducted to calibrate the impact velocity as this is not measured during normal operation of the rig. A high speed video was used to image the projectile through the muzzle vent holes from which the velocity was measured as a function of launch pressure. The acceleration and hence SRS generated along the central axis of the test item interface was recorded to provide data on the effect of varying the projectile mass, velocity and impact face pads.

The standard projectile is a steel rod weighing 3.7 kg. It has it has been shown that projectile mass can be used to vary the initial slope of the SRS up to the knee frequency [2]. Therefore a reduced length and lighter steel projectile weighing 2.25kg was also used (figure 2).

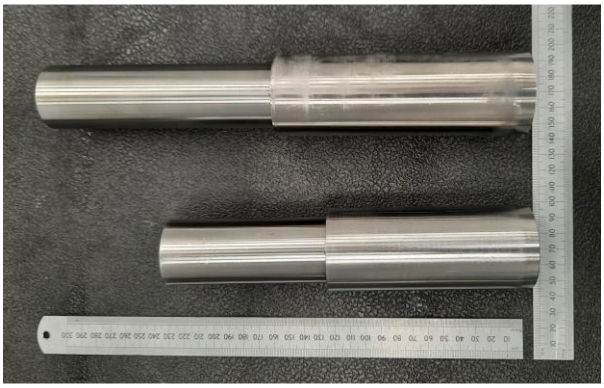

Figure 2 The two projectiles used, heavy (top) and light (bottom)

The impact configuration is shown in figure 3. This consists of the main reverberant plate to which is bolted a 25mm mild steel anvil. Loosely attached to this is an 18mm thickness, semi-consumable mild steel plate. This can form the impact face, in which case it is replaced depending on the rate of damage. In order to limit damage to the projectile a soft aluminium plate is also used, this has minimal effect on the output SRS. The 5mm plate of AA 1050 H14 is loosely attached to the face of the steel plate which largely eliminates damage to the projectile. Some tests were conducted with just the metallic impact plates but were limited to low velocity impacts and tend to produce a linear SRS with no knee.

Figure 3 Detail of the impact point showing from left to right, reverberant plate, bolted anvil, semi sacrificial steel plate, aluminium plate and rubber layer.

The SRS is tuned by changing the impact parameters to control the overall level of the SRS. Additional impact pads are typically EPDM rubber, Nylon and layers of paper. For the present study only rubber pads were used. The material is a 6mm thickness EPDM rubber with a Shore hardness of 70.

Figure 4 Test item interface plate with centrally mounted shock accelerometer aligned with impact axis.

Data was collected from a shock accelerometer (PCB 350CO3 10,000 g pk) positioned along the axis of the impact and attached by a dental paste adhesive to a steel interface plate (figure 4). Stud attachment is more typical but this test series was unusual as no mass simulator was present. This normally blocks a centreline mounting so that this position is not provided with a threaded location.

Data was collected on a Prosig P8048 system with processing to SRS being performed with Prosig DATS analysis software. The SRS analysis used the Smallwood algorithm over the frequency range 10 Hz - 10 kHz sampling the primary pulse for a duration of 1 ms.

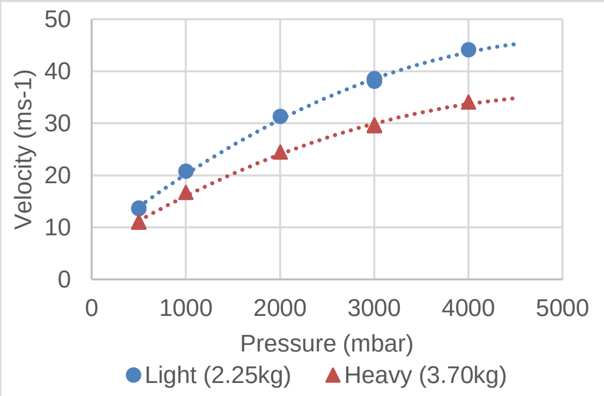

Figure 5 The effect of launch pressure on impact velocity

3. EXPERIMENTAL RESULTS

The effect of launch pressure on velocity was determined for the two projectiles masses and the data is shown in figure 5. The velocity data points derived from these tests was then used as the starting velocities for subsequent numerical models.

The SRS at the centreline accelerometer was recorded for a fixed impact condition (6mm EPDM rubber) for the range of impact velocities and the resulting SRS for the heavy 3.7 kg projectile are shown in figure 6. The effect of increasing velocity is to progressively raise the amplitude of the SRS cross the whole frequency range.

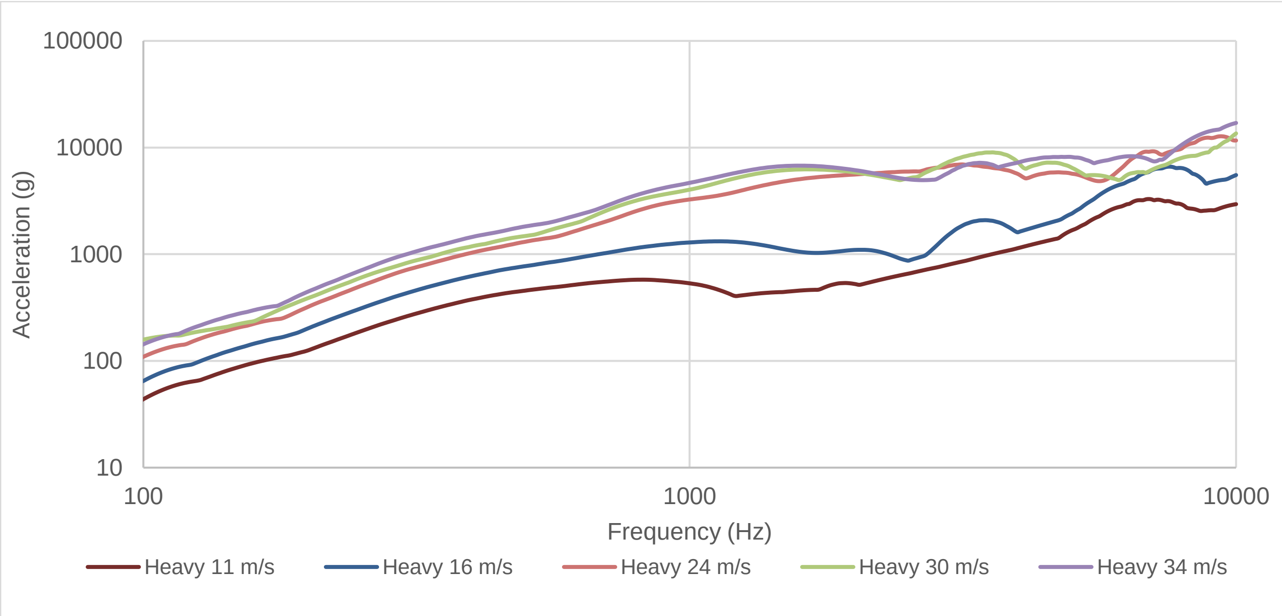

Figure 6 SRS for the heavy projectile over a range of impact velocities

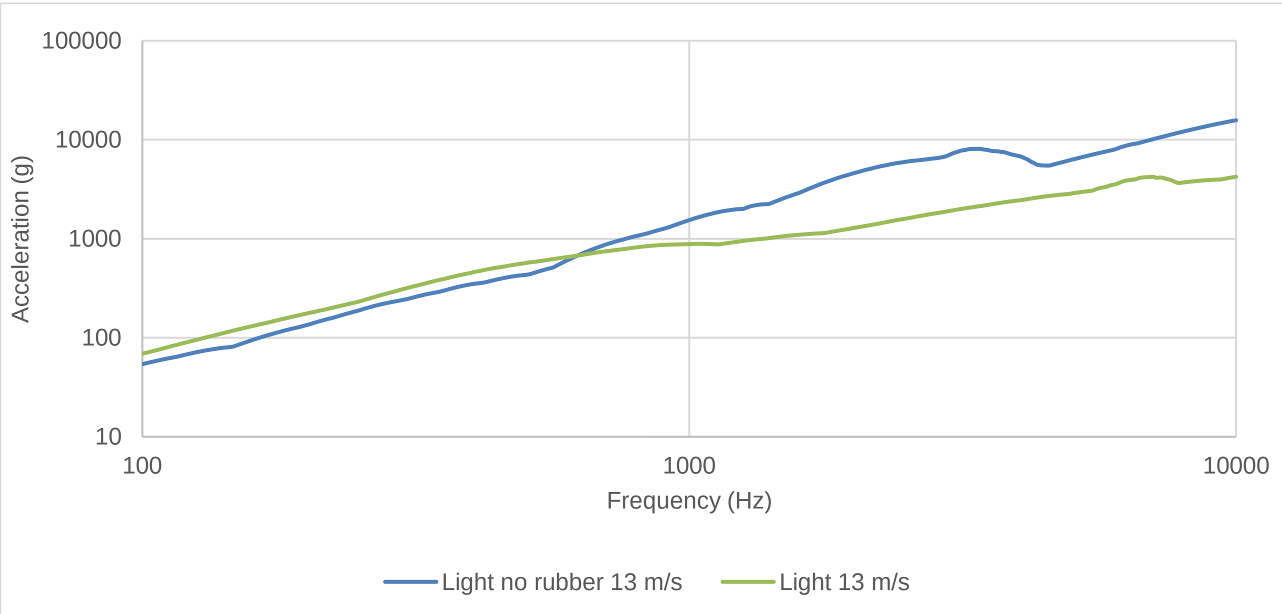

Figure 7 SRS for a 13 m/s impact with the light projectile and with or without an EPDM rubber layer

To determine the effect of the EPDM rubber layer a pair of tests were conducted at the lowest velocity with the light projectile. One test had only the aluminium sacrificial plate whilst for comparison a second test used the aluminium plate and the EDPM rubber. The resulting SRS are shown in Figure 7. The effect of the rubber on the SRS is to introduce a knee frequency at approximately 1000 Hz and reduce the amplitude at all frequencies above that point.

4. NUMERICAL MODEL DESCRIPTION

The numerical model was constructed in ANSYS using the CAD from the system manufacturer. After importing into ANSYS SpaceClaim, the components were simplified by the removal of all bolt holes to reduce the mesh complexity and allow relatively large elements to be used in the areas distant from the impact. A symmetry boundary was created along the central plane of the model (Figure 8). All bolted joints were set to bonded whilst the impact plate stack (semi sacrificial steel, aluminium, and rubber layers) were set to a frictional interface. The interface between the projectile and the first layer surface (rubber or aluminium) was also set to frictional.

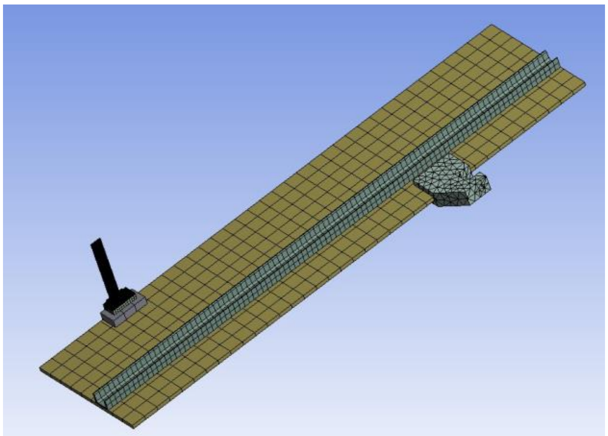

Figure 8 Complete meshed model of the reverberant plate, with centreline symmetry showing the anvil, plates and projectile.

The projectile was modelled as a solid cylinder of the same diameter as the impact end of the projectiles (39 mm) and the length adjusted to match the weight of each of the experimental projectiles (Heavy 3.7 kg and Light 2.25 kg). Some initial runs were conducted with modal and harmonic-response solvers but eventually all modelling was conducted in the explicit solver as the impact dynamics are the key part of this study.

All steel components were assigned to 4340 steel from the ANSYS explicit materials library and the aluminium plate was set as AA 1100-0 which is a close match to the 1050 H14 alloy used in the sacrificial aluminium plate. The rubber layer is not easy to model as it has to display complex non-linear behaviour under very high pressures and strain rates. It initially deforms and is then crushed and destroyed during the impact. The initial behaviour of the rubber could be reproduced by a 3rd order Ogden model (Rubber1-ANSYS Explicit Materials library) but this did not provide sufficient hardening as the deformation rate and magnitude increased and it ceased to behave realistically at the highest loads and loading rates.

A model for polycarbonate (Polycarb - ANSYS Explicit Materials library) was modified to provide reasonable agreement with the behaviour of the EPDM rubber. The polycarbonate model was tuned by reducing the shear modulus from 1 GPa to 55 MPa, whilst all other properties including the shock equation of state were retained at the polycarbonate values. The rubber layer was then meshed at a 1mm element size (Figure 9) and an erosion strain was set at a geometric strain limit of 3 to remove highly deformed elements as the test progressed.

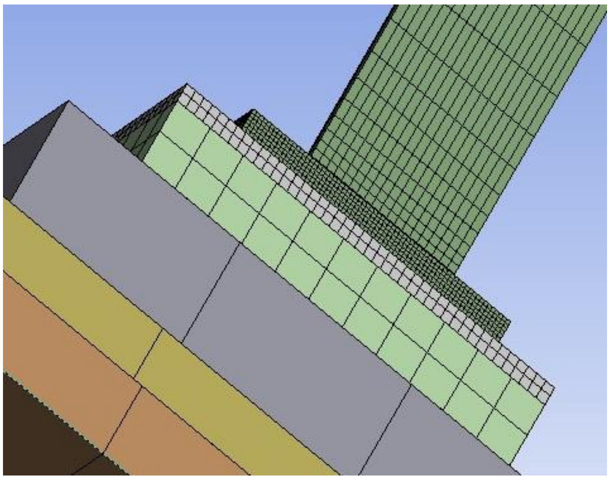

Figure 9 Close up view of the impact area and projectile to illustrate the meshing of the different components, with the projectile (top right) nearly in contact with the rubber pad.

The model was run using the same impact conditions as the experimental series with both projectile weights. A full set of runs were competed with the rubber layers and for comparison some were conducted without the rubber layer. Acceleration data was collected from a probe on the face of a 4mm cube at the experimental accelerometer location and acceleration data was then processed to produce SRS using the same Prosig DATS analysis routine and settings as used for the experimental data. The model run period was 1 millisecond during which 5000 data points were recorded.

5. NUMERICAL MODEL RESULTS

The effect of velocity on SRS is shown for the set of tests with the heavy projectile in Figure 10. When compared to the experimental data in Figure 6 it is apparent that the amplitude of the SRS is approximately an order of magnitude lower but the form and main characteristics of the SRS appear correct. The relative spacing of the curves as a function of velocity is very similar as is the slope on each side of the knee frequency.

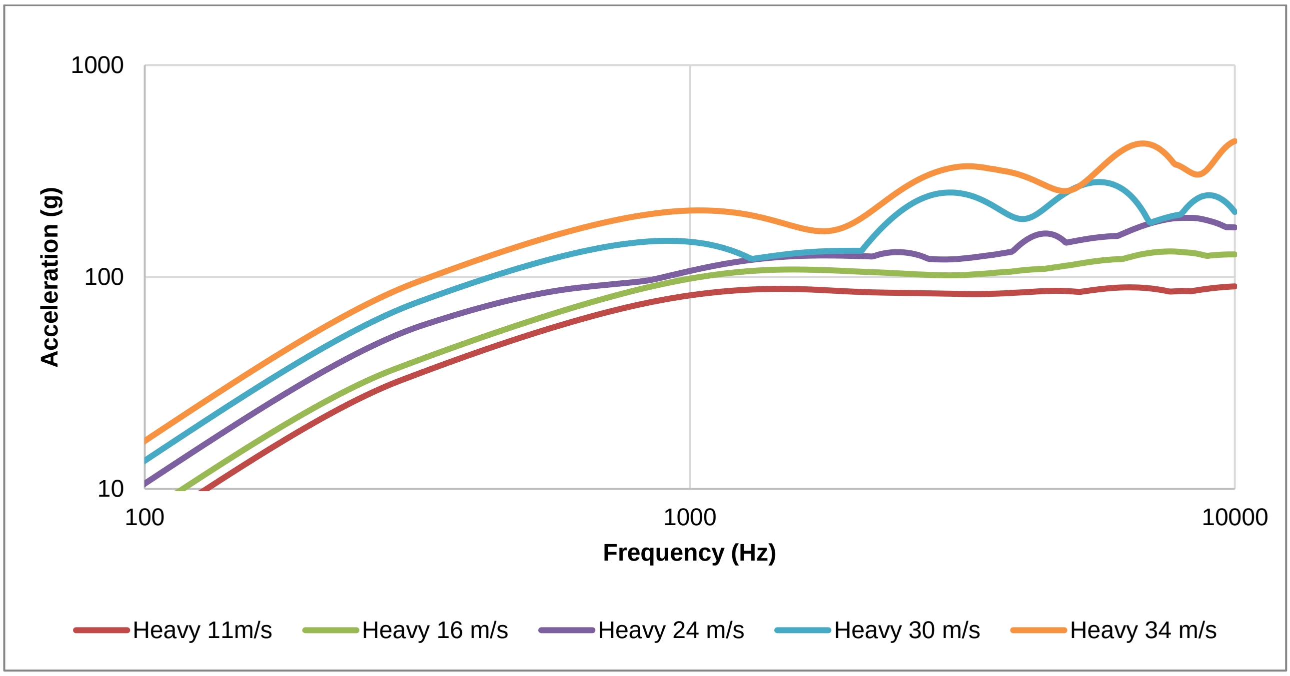

Figure 10 SRS for the numerical model of the heavy projectile with the same conditions and velocities as the experimental data in figure 6

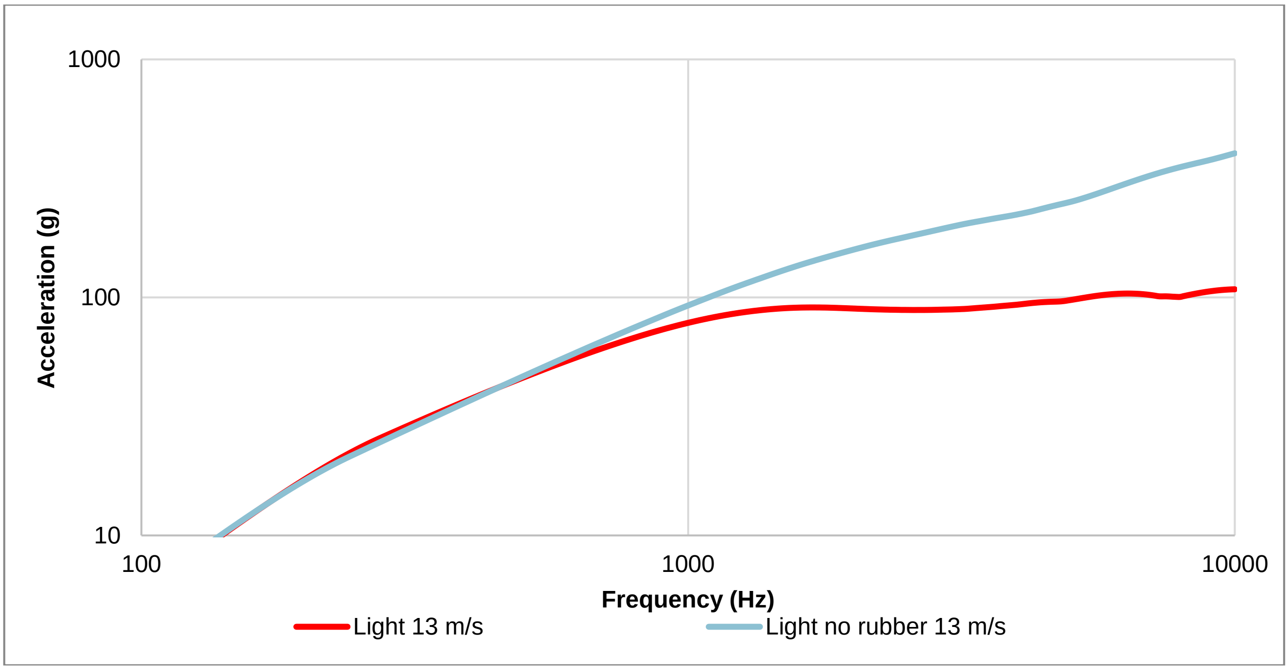

Figure 11 Numerically derived SRS for a 13 m/s impact with the light projectile and with or without an EPDM rubber layer

To examine the effect of the rubber layer a pair runs were conducted within the numerical model with the light projectile at 13 m/s with or without the rubber layer. The resulting SRS are shown in figure 11 and can be compared to the experimental data in figure 7 Again in comparison with the experimental data the numerically derived SRS is approximately one order of magnitude lower although the relative spacing, slopes and knee frequency are in line with the experimental data.

6. DISCUSSION

The experimental programme provided useful data on the variation of SRS and acceleration characteristics over the full range of impact velocities for the standard and lightened projectile. Repeatability between tests was good as shown in Figure 12. which is for two tests under identical conditions that were conducted at the start and end of the experimental trial (3 days apart). The data here is plotted against an illustrative target SRS to demonstrate the normal output of the test.

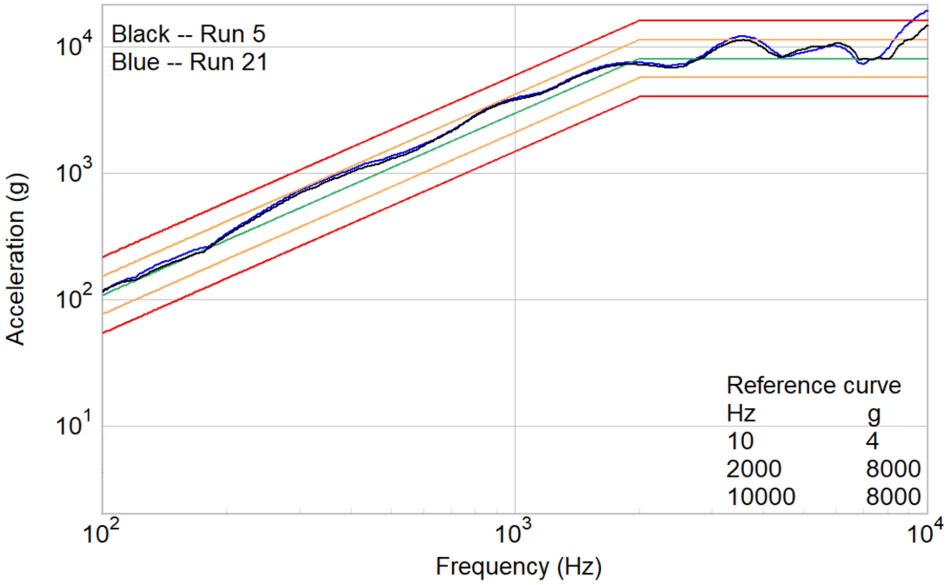

Figure 12 Plots of SRS of two identical tests superimposed on a target SRS.

It is useful to compare the time histories of the rubber vs no rubber tests for the experimental and numerical model. Figure 13 shows the time history for the experimental test. For the impact on the aluminium (no rubber) the pulse approximates to a square wave at very high amplitude of 20,000 g whilst the rubber layer reduces the peak to approximately 4000 g.

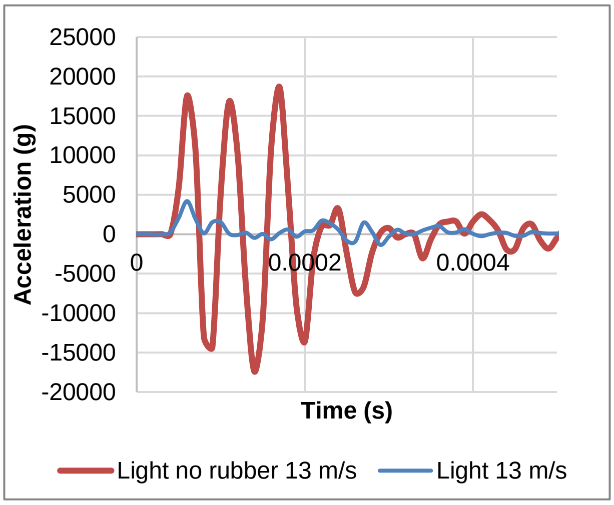

Figure 13 Experimental data comparing the acceleration/time history for a 13 m/s impact with the light projectile with or without a rubber layer

This can then be compared to the same test conditions in the numerical model (Figure 14). The acceleration levels in the numerical model are approximately half those of the experimental data. It is also evident that the numerical data shows significantly less reverberation.

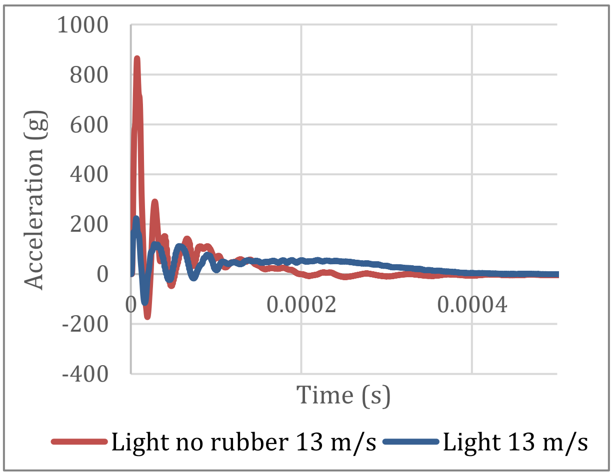

Figure 14 Numerical model data comparing the acceleration/time history for a 13 m/s impact with the light projectile with or without a rubber layer

The effect of the rubber layer in the numerical model is proportionately similar to the experimental data. The rubber layer reduces the peak acceleration amplitude by a factor of approximately 4, the same factor as the experimental result. The later stage broad low-amplitude peak is of a similar relative amplitude and duration between numerical and experimental data. Finally the SRS comparison (figure 7 and figure 11) also show that the numerical rubber model is a good approximation of the real material behaviour. Figure 15 shows the model at the end of the run where the rubber has been completely destroyed at the impact site. This matches the experimental behaviour where only rubber crumb remains after a test.

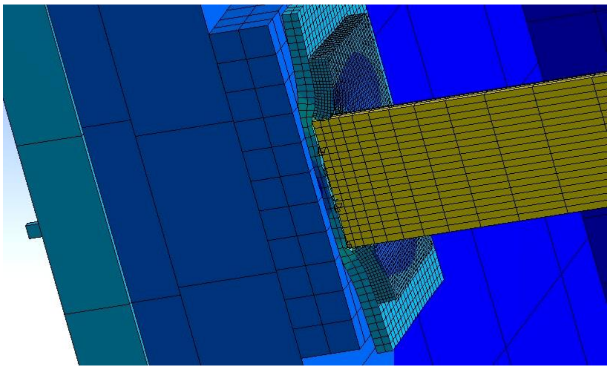

Figure 15 Numerical model of a light projectile impact at 38 m/s showing complete disruption and numerical erosion of the rubber layer

In the present study a model has been demonstrated that reproduces the effect of the key variable used to tune to a target SRS. The model is not required to produce an accurate reproduction but rather to provide a better estimate of the effect of available user inputs. It is intended that it will be used to provide indications of the most likely successful test characteristic and therefore reduce the number of experimental tests required to refine a solution. Additional work is needed to refine the impact model and in particular to provide models for a wider range of impact pad materials such as paper layers.

7. REFERENCES

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